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#### How to cite:

Norton, A. J. (2018). A Zooniverse Project to Classify Periodic Variable Stars from SuperWASP. Research Notes of the AAS, 2(4), article no. 216.

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Version: Accepted Manuscript

Link(s) to article on publisher's website:

<http://dx.doi.org/doi:10.3847/2515-5172/aaf291>

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A *Zooniverse* project to classify periodic variable stars from *SuperWASP*

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( Received ???; Revised ???; Accepted ???)

Submitted to RNAAS

*Keywords:* binaries: eclipsing — stars: rotation — stars: variables: general — surveys

## 1. *SUPERWASP*

The Wide Angle Search for Planets – *SuperWASP* – is the world’s leading ground-based survey for transiting hot Jupiters (Pollacco et al. 2006). Based at two sites, and operating from 2004 – 2013, the project accumulated  $\sim 16$  million images from  $\sim 2800$  nights, comprising  $\sim 580$  billion data points from  $\sim 31$  million unique objects. The whole sky has been surveyed, excluding the Galactic Plane where the stellar density is too high to resolve individual objects, given the large pixel scale. To date, the project has announced the discovery of  $\sim 160$  exoplanets.

The *SuperWASP* data also provide a unique archive for variable star research. Combining both short cadence and long baseline, and covering all stars away from the Galactic Plane between about  $V = 8 - 15$ , it offers great opportunity for studying both large classes of objects and for discovering rare individual systems.

An initial period search, using the first few years of data, yielded many potentially periodic objects. Following this, a preliminary machine learning investigation attempted to classify the folded lightcurves using a neural network (Payne, 2012). This was only partially successful, but nonetheless enabled investigations of subsets of the data. Highlights included: identifying 140 short-period eclipsing binaries, so increasing the number of main-sequence systems known close to the period cut-off by  $10\times$  (Lohr et al. 2013); discovery and characterisation of the first doubly-eclipsing quintuple system (Lohr et al. 2015a); measuring period changes in  $\sim 14000$  eclipsing binaries which may indicate the presence of third-bodies in 25% of the systems (Lohr et al. 2015b); studying period changes in eclipsing sdB star post-common envelope binaries to search for circumbinary exoplanets (Lohr et al. 2014); the discovery and characterisation of a high amplitude  $\delta$  Sct star in an eclipsing binary (Norton et al. 2016); and studying  $\sim 5000$  RR Lyrae stars, including the identification of  $\sim 800$  Blazhko effect systems, most of which are newly identified (Greer et al. 2017).

## 2. *ZOONIVERSE*

Now that the observational phase of *SuperWASP* has completed, we recently performed a re-analysis of all 31 million lightcurves. The period searching used a combination of CLEANED power spectrum analysis and a phase dispersion minimisation folding analysis, and was sensitive to periods between  $\sim 1$  hour and  $\sim 1$  year. As a result, we identified  $\sim 8$  million potential periods in  $\sim 3$  million objects. However, significant numbers of these are close to integer fractions or multiples of a sidereal day or lunar month, and so are most likely to be spurious and caused by systematic noise. Omitting these “flagged” periods leaves  $\sim 1.6$  million periods in  $\sim 0.8$  million unique objects. It is only these latter “unflagged” periods that are the subject of the *Zooniverse* project described here.

*Zooniverse* is a multi-disciplinary citizen science portal, hosting numerous projects to identify and classify different phenomena, across all areas of science. Recently, the *Zooniverse* team instigated a project-builder interface allowing anyone to build their own project. We have now done this, using images of the folded *SuperWASP* lightcurves as the classification objects.

Because *Zooniverse* projects are open to everyone, the classification tasks must be straight-forward and not depend upon subject-specific knowledge. Consequently we have devised a simplified scheme to classify *SuperWASP* folded lightcurves. When users visit the project at: <https://www.zooniverse.org/projects/ajnorton/superwasp-variable-stars> they are presented with a tutorial that guides them through the classification process; a field-guide is also available which presents samples of lightcurves of each type. The classification task asks users whether each folded lightcurve resembles that of an EA or EB type eclipsing binary; an EW type eclipsing binary; a pulsating star; or a generic rotational modulation. Options for unknown variable types or “junk” are also available. In the case of eclipsing binary lightcurves, often the period at which the data are folded will be half the genuine period. Furthermore, in both eclipsing systems and pulsating systems, sometimes the identified period is clearly incorrect. Consequently, a subsequent question asks the user whether they believe the period is correct, half the true period, or incorrect.

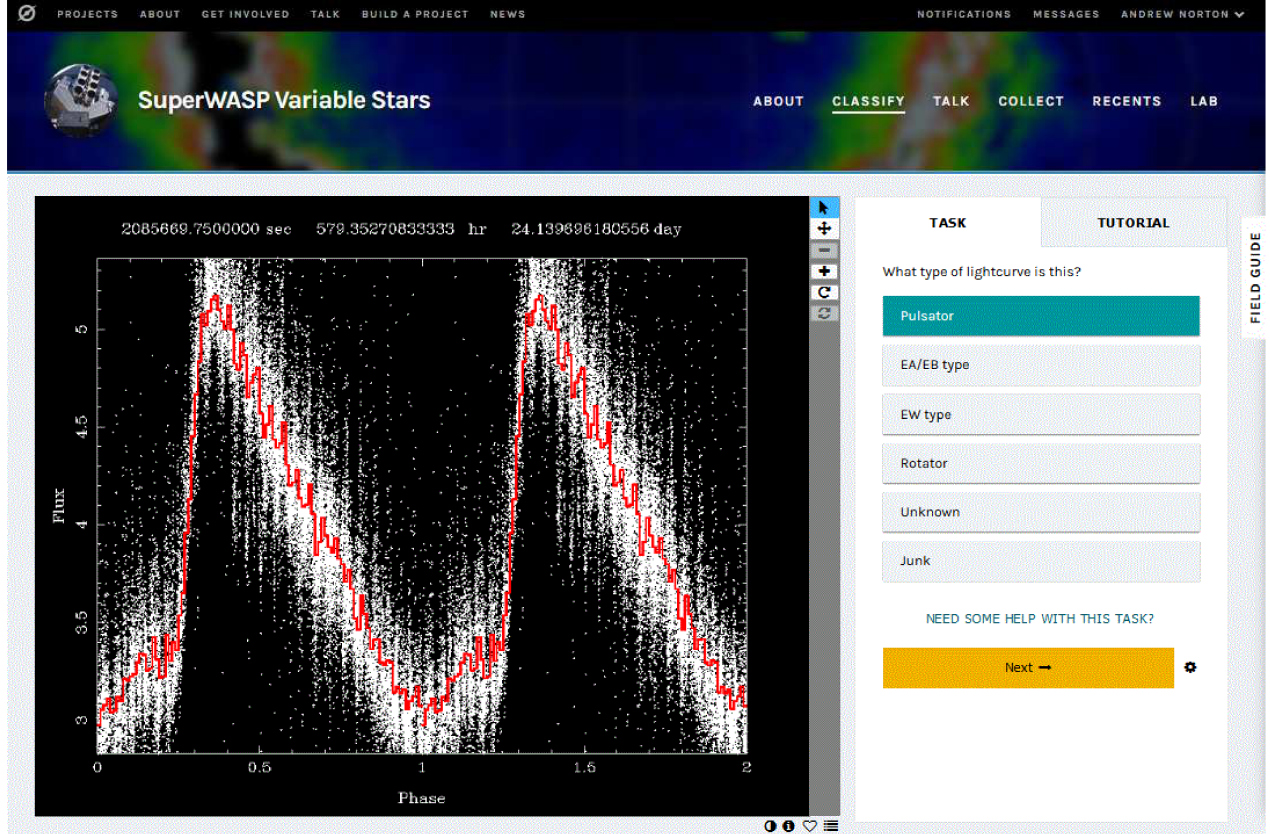


Figure 1. The *Zooniverse* interface to the *SuperWASP* variable stars project

Once the lightcurves have been classified (by  $\geq 5$  people per image), we shall construct catalogues of the various object classes, which can be refined further by subsequent cross-correlation with other catalogues. This will allow the range of observational parameters for each class to be identified, and also allow the discovery of individual “keystone” objects with unique features. Scientific topics for ongoing investigation may include: exploration of the evolution of stellar system architectures through the identification of imminent mergers and hierarchical multiple stars; identification and analysis of large samples of pulsating stars with varying periods and amplitudes; searches for circumbinary objects and companions to pulsating stars; and the identification of unique and extreme objects including very long period contact binaries, very short period detached binaries, eclipsing binaries in highly elliptical orbits, or extreme amplitude pulsating stars.

This *Zooniverse* project was developed with the help of the ASTERICS Horizon2020 project. ASTERICS is supported by the European Commission Framework Programme Horizon 2020 Research and Innovation action under grant agreement n.653477

The *SuperWASP* project is currently funded and operated by Warwick University and Keele University, and was originally set up by Queen's University Belfast, the Universities of Keele, St. Andrews and Leicester, the Open University, the ING, the IAC, SAAO and STFC.

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